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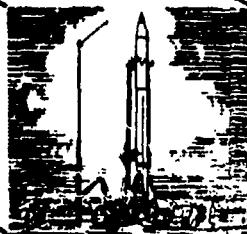


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PROGRESS IN MINIATURIZATION AND MICROMINIATURIZATION (U)

JULY - SEPTEMBER 1959

Compiled by T. M. Liimatainen

FOR THE COMMANDER
Approved by

Maurice Apstein
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Associate Director for
Supporting Research



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ABSTRACT

(U) This report describes briefly the significant accomplishments and progress made in miniaturization work at this installation during the period 1 July 1958 through 30 September 1958. Following the outline of the second annual report ~~DOFL TR-466~~ on this same general subject, information is presented under the following three headings: (1) systems, (2) components and assemblies, and (3) methods, processes and techniques.

(AD-312 162)

1. INTRODUCTION

(U) Two annual reports of the DOFL microminiaturization program have appeared previously. The first (ref 1) presented a brief historical introduction to DOFL work which fell in the general area of miniaturization, and described recent developments in the specific area of microminiaturization up to June 1958. The second annual report (ref 2) covered developments in the area of microminiaturization in the period June 1958 through June 1959.

(U) This present report is a quarterly report, the first of a series of quarterly reports planned for FY 1960 in order to provide timely summaries for all sponsors of the DOFL microminiaturization program.

2. SYSTEMS

2.1. Light-Weight GM Fuzing System (Copperhead)

(C) A display model to illustrate the physical characteristics of a lightweight integrated fusing device, arming programmer, and power supply for use on tactical missile weapons was delivered to ORDTN in February 1959. This model weighs only 15 lb compared with 60 lb for the Little John Adaption Kit. It consists of dual channels, each containing (a) a safety mechanism and arming programmer, (b) a UHF Cobra-pulse fuze, (c) an electronic time fuze having an accuracy of 0.1%, and (d) a 32-watt battery, ¹ supply weighing approximately 0.8 lb. Power the integrated system and the warhead initiation circuits (see Fig. 2, item 1.1). Satisfactory laboratory operation has been demonstrated for nearly all system components. Fabrication of fifteen flight models was started for performance evaluation of the Copperhead System in the Picatinny research vehicle.

(C) The system design is based upon the following performance:

1. Time fuze with an accuracy of 0.1 sec for ranges corresponding to flight times from 3 to 45 sec.

¹The weight of the Little John power supply is approximately 8 lb.

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2. Radio fuze for extended ranges (45 to 110 sec) with selectable burst heights ranging from ca 100 to 1100 ft.
3. A near-surface burst fuzing function, to be incorporated in the final design.
4. Operation over the full military temperature range with a reliability of 99%.
5. Maximum immunity against countermeasures.

2.2 The Cigarette Fuze

(U) Plans are under way to incorporate this subminiature proximity fuze in a weapon system (Davy Crockett). Since performance details of this fuze are classified "SECRET", further information is not given in this document but appears in references 3 and 4.

2.3 Radar Range Finder

(U) This system is a hand-portable, battery-powered, radar range-finder which should have wide application wherever accuracy and light weight are premium requirements, for example in artillery and weapon systems of the Davy Crockett type. The short pulse radar operates with a pulse of 10 μ sec and 100 w, developed and processed in an electronic package that is smaller than a shoebox and weighs only 7 lb (see ref 2, item 1.3).

(U) Since July 1959, some defects in the scope indicator unit have been corrected. The counter has been reconstructed to correct erratic behavior and to increase reliability. Operational system tests were conducted. In these tests, certain defective components were located and replaced. The major difficulty was a time jitter in the range delay generator over about 2/3 of the expanded R sweep. A concentrated effort is being made to eliminate the jitter, either by employing a magnetostrictive delay line and avalanche transistor circuit or by replacing the phantastron circuit.

2.4 Radar Altimeter (Jupiter)

(U) In reference 2, item 1.5, it was reported that two models of a simplified, self-telemetering, trajectory altimeter were delivered to ABMA. Difficulties were encountered in the power supply. These are being corrected.

2.5 Radar Altimeter (Pershing Types I and II)

(C) Two additional miniaturized altimeters are being designed, developed, and tested. Type I is intended to be an airborne package, approximately 15 lb in weight and 200 cu in. in volume which will provide continuous altitude information from 50,000 ft to below 1,000 ft.

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with an accuracy of 15 to 30 ft. A transistorized crystal-controlled time-base, and a pulse modulator, have been developed. Work has been initiated on a miniaturized version of the oscillator cavity. A time interval computer and a modulator of higher power are under development.

(C) The Type II altimeter is being designed for a system weighing approximately 2 lb and having a volume of approximately 125 cu in. This device will provide altitude information of the same type as that of the prior model. In order to obtain maximum reduction in weight and volume, some unorthodox miniaturization schemes are being considered. The possibility of incorporating the transmitter within the antenna is being explored. Also, the possibility of incorporating the first stage of the receiver in the transmitter or in the antenna cavity is being considered. A survey of low noise, high gain transistors at 1000 mc is being made. If a type of transistor now under development proves to be successful, it may be possible to repackage an existing 40 cu in. receiver in a volume of about 5 cu in. Semiconductor modulators that use magnetic techniques for pulse sharpening will be investigated. The power requirements of the system will be kept to a minimum in order to reduce the weight and volume requirements of the power supply equipment.

2.6 Radar Beacon

(U) In reference 2, Paragraph 1.6, preceding work on the radar beacon was described.

(U) A prototype model of a modulator that uses solid state devices in place of a Thyatron was constructed. The performance of this modulator was compared with the performance of modulators available from certain vendors. Efforts to reduce the size and weight of the modulator are being continued.

(U) Development of a C-band triode of the required bandwidth is proceeding. A survey of available C-band triodes has been made. Present models fail to meet requirements in the following areas:

- (a) Tubes of the same type vary considerably in their parameters. Tuning is difficult.
- (b) Efficiency is very low, roughly 5%.
- (c) Tube life is too low at required power and duty cycle (400 w peak power, 1.042 duty cycle).

2.7 High G Altimeter

(U) This project is designed to develop a total landing rate of one gaseous oxygen monoflame. It is 3-1/2 in. in diameter, 2500 ft/sec. flight velocity gas goes through spark plug gap ranges of 170-230.

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Temperatures up to 1500°C and pressures of several atmospheres will be measured. Launching forces up to 200,000 g are anticipated.

(U) A transistorized 70-kc subcarrier oscillator and a vacuum tube thermocouple telemeter have been fabricated and tested. No salient problems remain in the basic circuit design. Two major technical problems exist: (1) to find or develop components that will withstand the high-g shock and (2) to test the components and the complete system.

(U) Several types of transistors have been tested; others are scheduled for test in the near future. Potting material is being developed and tested.

(U) A ferrite-H-core rf oscillator was tested at 80,000 g. The oscillator survived impact in operating conditions but the frequency shift was found to be unsatisfactory. Further development will be undertaken.

(U) A temperature transducer for heat transfer measurements of the stagnation point of a missile in flight is being developed, calibrated, and tested.

(U) Investigations of the facilities available for the testing of components and systems under high-g conditions are being made.

3. COMPONENTS AND ASSEMBLIES

3.1 Millimeter Magnetron

(C) Successful operation of a miniature 4 mm, 70 kc magnetron was reported in reference 2, item 2.3. This tube produced 1 kw peak output at 10% efficiency with 3500 v applied. The weight of the package was only 2.5 lb.

(C) The lifetime of the first operating magnetron was very short because of loss of emission from a marginal cathode. A nickel-oxide matrix cathode has been substituted and it has substantially improved emission. It operates at a lower filament temperature over a longer period of time. Output power of the new cathode is about 109 w. It is expected that this power can be raised by making small changes in electrical design.

3.2 Microwave Strip Line

(U) Photo-etched, flat coaxial, strip-line components are being investigated as substitutes for standard rectangular microwave circuit components. Use of these strip-line components will enable more than a 50% reduction in size and weight of an rf head assembly (see ref 2, item 2.6).

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(C) Two strip-line rf heads for the Little John T-2074 (XM7) fuze were received from the contractor. Figure 1 compares the strip line model with the waveguide assembly. The contractor's model exhibited excess rf leakage, due to the large number of adjustments. Redesign was started at DOFL to improve the performance and reduce the size and weight by a factor of two. The resulting package should be 5 in. in diameter and approximately 2 in. in height.

(C) An antenna system was started for the lightweight fuze. Antenna patterns were taken using the printed spiral as the basic element. Component development work was begun on a strip-line rf head for the Coral system.

3.3 Pure Pneumatic Computer Elements

(U) Experimental models of purely pneumatic computer elements have been devised. They can accomplish a variety of logical functions without moving parts. Amplification, feedback, digitalization, proportioning, memory, and normal mathematical computation functions have been accomplished. It is possible to design pneumatic analogs of most electronic circuits at frequencies up to 20 kc. The pneumatic equivalents offer advantages of extreme ruggedness, reliability, ability to serve large forces, nuclear invulnerability, easy production lot quality control and testing, low cost, indefinite shelf life, high density power supply, and, in some cases, use of environment as direct input data and/or power supply. These advantages suggest wide application in weapons systems. Work has been started on templates to permit application of printed circuit techniques in production of these elements (ref 5).

3.4 Electronic Programmers

(U) A miniature timer has been designed for use as a programmer and time fuze. Its volume is approximately 10 cu in., and its encapsulated weight is approximately 10 oz. It utilizes printed circuits and miniature transistors, and consists of 22 miniature binary flip-flop circuits fed by a crystal-controlled oscillator. The outputs are recognized by miniature NOR circuits, which in turn control switching transistors. One prototype model of this design has been fabricated by a contractor and delivered to DOFL for evaluation. Six more prototype units are in process of fabrication by the contractor.

3.5 Power Supply

(U) Experimental treatments of electrodes have resulted in improved current density, i. e. an increase from 0.05 amp/sq in. to 0.5 amp/sq in., at temperatures down to -33°F, in silver-oxide-zinc reserve batteries (see ref 2, item 2.13). Potassium hydroxide and other electrolytes are being investigated; rubidium hydroxide and cesium hydroxide show promise of higher conductivity at very low temperatures. An activation scheme, which involves vacuum filling of

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FIGURE 1. - Little John fuse r.f. heads: (left) waveguide r.f. head; (right) st. waveguide head.

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a common chamber containing a series-connected stack of silver oxide and zinc plates separated with a suitable material, is being investigated. Experimental and prototype devices incorporating these developments are being produced for evaluation prior to application in the light weight fuse system.

3.6 '2-D' IF Amplifier

(U) An investigation is being conducted to determine the practicability of constructing IF amplifiers in the "2-D" form. The design objectives are: (1) a gain of about 100 db, (2) a center frequency of about 30 mc/sec, and (3) a volume of a fraction of a cubic inch. The circuit under study employs 2N700 transistors in a common emitter configuration. The stages are not neutralized and simple fixed-tuned transformer interstage coupling elements are employed.

(U) Single operating stages have been constructed on ceramic plates which measure 0.750 x 0.750 x 0.020 in. Cased transistors are employed so that the advantages of the extreme thinness of the wafer have not yet been realized. Individual stage gains of 20 db have been achieved. An IF amplifier in "2-D" form is shown in Figure 2. The inter-stage transformers are a key element in this design. The toroidal transformers have an o. d. of 0.200 in. and a thickness of 0.040 in. Cores of Teflon powdered iron, and ferrite have been tested. Such a transformer appears in the center section of Figure 3.

(U) Transistors having a thickness of about 0.040 in. have been fabricated from commercial 2N700 transistors. This was accomplished by pouring potting material into the case of the transistor, curing, and then slicing through the case immediately above and immediately below the transistor die. At the top of Figure 3, there is shown a transistor which has been so treated. Connection is then made to the portions of the three relatively large-diameter header-lead-through wires which appear adjacent to the die.

(U) A new "2-D" layout is being fabricated on a wafer of dimensions 0.600 x 0.600 x 0.020 in. If an over-all stage thickness of 0.060 in. can be maintained, then a five-stage 100-db amplifier can be built in a volume of about 0.1 cu in.

(U) Studies are also under way to determine the best shielding methods. The present technique involves dipping the individual stages in an insulating medium and then copper-plating to provide the shielding. Smaller toroidal transformers are also being investigated. The major problems will lie in maintaining amplifier stability and providing proper frequency response with fixed tuning.

3.7 Digital Electronic Program Timer

(U) A digital electronic program timer employing commercially available subminiature parts was built to demonstrate the

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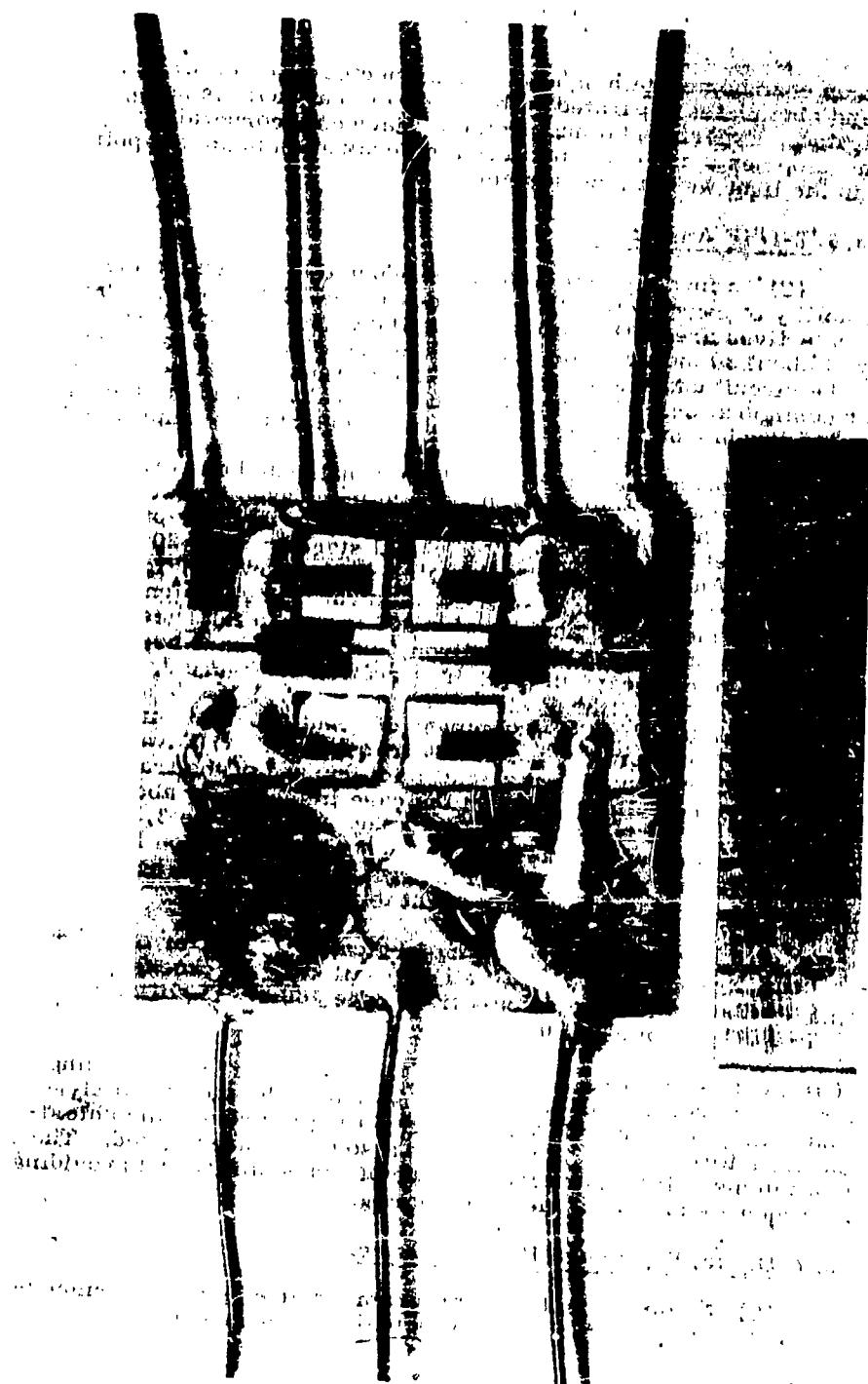


Figure 2. - 3L Mc. I. F. amplifier in "2-D" form: (upper left) I. F. transformer; (lower left) potted sliced transistor; (right) capacitors, resistors and printed wiring.

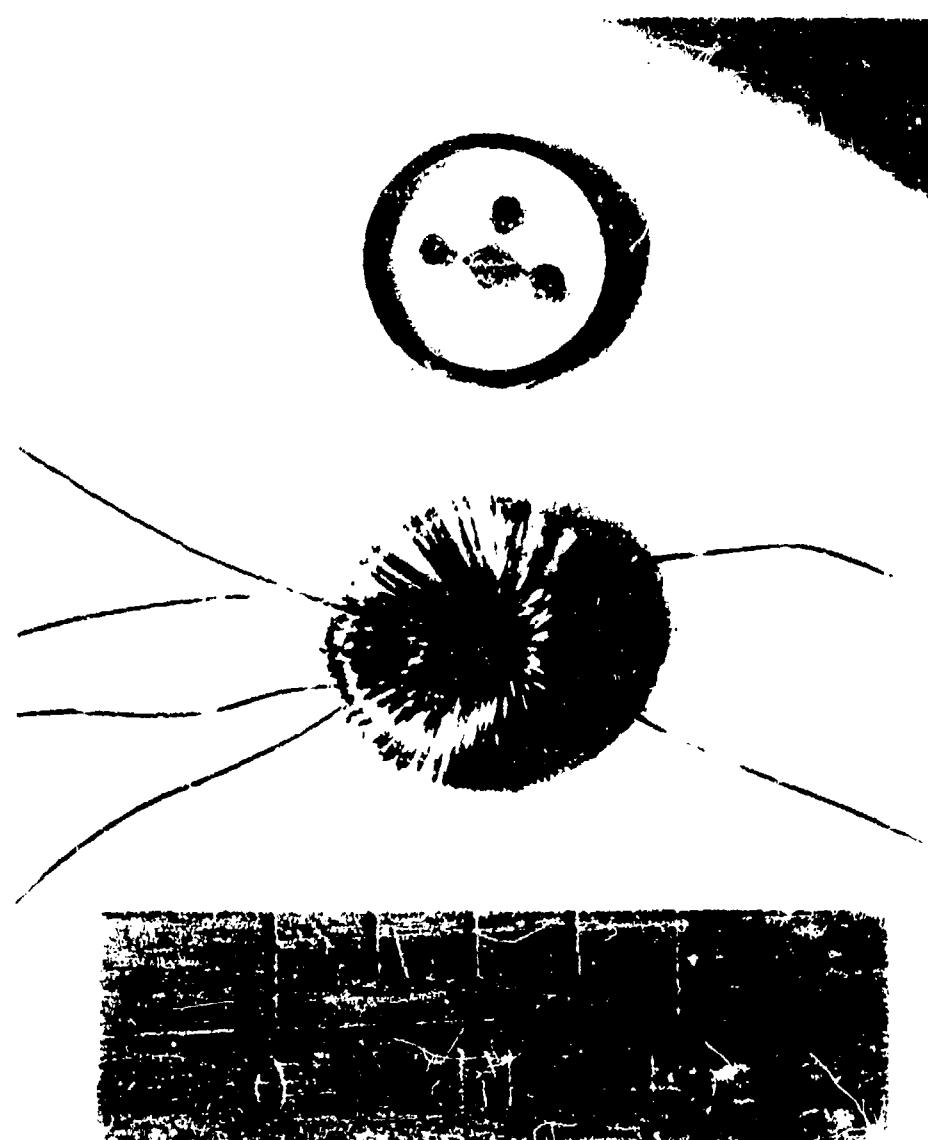


Figure 3. - Interstage transformer (center) and potted sliced transistor (top) for I. F. amplifier.

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feasibility of replacing mechanical program timers with electronic timers. The electronic timer provides five output pulses at fixed time intervals with respect to the last pulse. In addition, the interval between the time of starting the timer and the time of generation of the last pulse is variable from 0 to 204.8 sec in steps of 0.8 sec. This variable time is capable of being set from a remote point in less than 0.5 sec. The accuracy of this timer, excluding clock inaccuracies, is inherently limited to +0.0 or -0.8 sec. Greater accuracies can be obtained by adding binary divider stages and using a higher frequency, more accurate, timing oscillator.

(U) The packaged system contains 49 transistors, occupies a volume of 4.12 cu in. and represents a packaging density of over 110,000 components per cu ft. (see fig 4). When multicomponent "2-D" printed wafers become available, a further volume reduction of 10:1 will be possible. This development is described in detail in reference 6.

3.8 AC Signal Comparator

(U) A specialized, transistorized voltage comparator has been developed. The unit is designed to measure the difference in amplitude between two signals of the same frequency and to determine which of the signals is larger. The first model used two amplifiers with similar gain curves and compared their output. The dynamic range of these amplifiers was about 80 db and adjustment of the two amplifiers to obtain the desired similar characteristics was very difficult. The new device uses one amplifier and switch between the two signals and thus eliminates any need to balance the two high-gain amplifiers.

(U) The unit operates with a signal frequency of 28 kc and incorporates automatic gain control. The sensitivity of the system is such that unbalances of about 2 μ v at an input level of about 100 μ v provide a readable meter deflection of several microamperes. The switching frequency is about 100 cps. Power requirements are 12 v at about 40 mA (ref 7).

3.9 Troubleshooting the DOFL "2-D" Binary Counter

(U) The DOFL "2-D" binary counter is more difficult to trouble shoot than the type of package containing commercial components because not all circuit points are available for measurement. A study has been made of the waveforms, resistances and voltages at the available terminals of the "2-D" wafer and these are used to diagnose component failures. Complete waveforms and measurements are given in a report which is now being prepared for publication (ref 8). The operation of the unit is explained in a non-mathematical fashion.

3.10 Micraamp

(U) A DOFL microminiature lamp is shown in figure 5, mounted in the lower right-hand corner of a "2-D" binary divider circuit.

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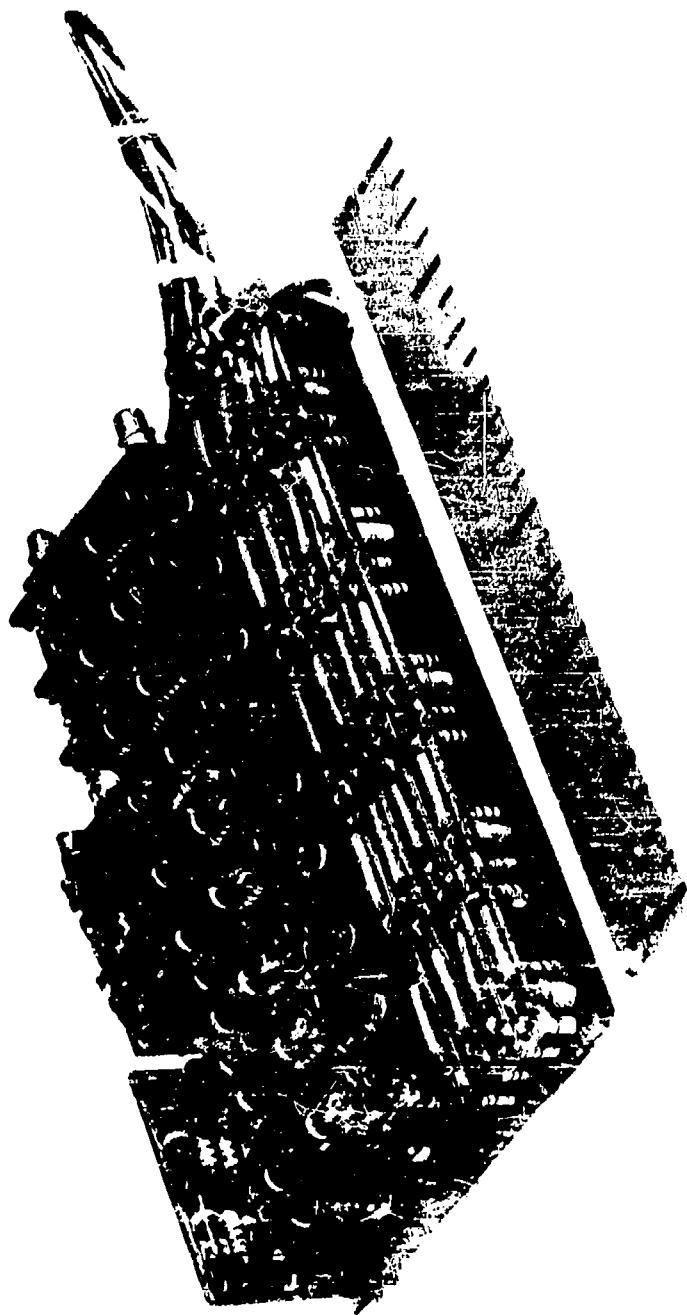


Figure 4. - Digit electronic program timer comprising 49 transistors and 219 associated parts.

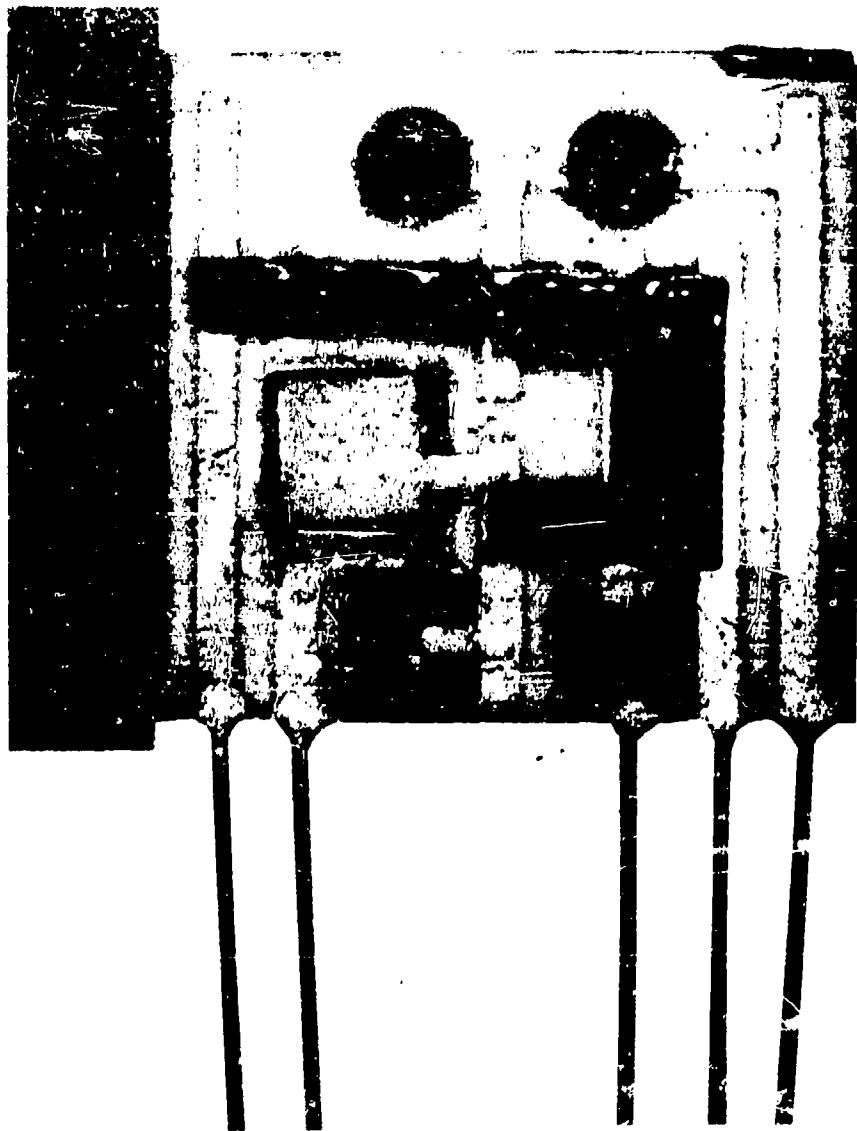


Figure 5. Micro-lamp (lower right edge) mounted in a "2-D" binary divider circuit.

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This "Microlamp" is somewhat smaller than earlier models and measures 0.020 in. in diameter by 0.090 in. in length. The lamp operates in the range 1.0 to 1.5 v. at currents of 25 to 30 ma, respectively, can be switched on and off up to a frequency of 100 cps, and has sufficient light intensity to be easily visible from any point in a normally lighted room. Because of its small size and low power requirements, this lamp is suited to many applications employing microelectronic circuitry, for example, for reading out timer and computer information, and for built-in test lamps to indicate the proper functioning of various sections of complex circuitry (ref 9).

3.11 High Frequency Diffused-Base Transistors

(U) Photo-engraving techniques have been employed in the fabrication of diffused base transistors, and in the extension of these techniques to assembly of the transistors as an integral part of two-dimensional printed circuit wafers (see ref 2, item 2.8). Transistors with emitter and base contacts of dimensions 0.002 x 0.006 in. were constructed in the past quarter. Vacuum deposited leads were used to make contact between base and emitter bars and header leads. This construction provides a solid and rugged unit which is being evaluated for high frequency performance and resistance to high shock. Electrical tests thus far show an alpha cut-off of 280 mc with an alpha of 0.928 at an emitter current of 3 ma.

3.12 Tunnel Diode

(U) A new type of semiconductor device known as the "tunnel diode" or the "Esaki diode" has a number of interesting properties, as follows:

1. Stable negative resistance characteristic.
2. Relatively insensitive to changes in temperature.
3. Insensitivity to semiconductor surface conditions (due to high impurity concentrations).
4. Operation in high nuclear radiation environment.
5. Very high frequency operation; oscillation up to 10,000 mc has been reported.
6. Fast switching speed (kilomegacycle rates have been mentioned).
7. Noise almost as low as that of masers and parametric amplifiers.
8. Adaptability to simple circuitry for performing most of the types of functions needed in small signal devices.
9. Very low power consumption.
10. Very small size, hence adaptability to micro-miniature circuits.

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(U) These properties are obtained because this device uses the majority carriers and functions by "quantum mechanical" tunneling.

(U) Germanium tunnel diodes built at DOFL exhibit peak currents in the range 200 μ a to 200 ma and appear to be rugged and stable. The principal limitations of these devices are: (1) a limited voltage region of 50 to 350 mv (with a few ohms of negative resistance), and (2) a high value of junction capacitance. However, the limitations may be overcome by operation of suitably designed circuits. The tunnel diode should be useful in "2-D" circuits because of the very low power required, and freedom from heating problems in very compact assemblies.

3.13 NOR Semiconductor Solid Circuit

(U) A NOR solid circuit was designed and fabricated. The NOR circuit was chosen as the simplest building block for solid circuit fabrication on diffused base germanium. This circuit contains four resistors, and one transistor. It functions as a multiple input inverter in that a voltage on one input or on both inputs results in zero output, whereas zero input gives a voltage output. This function is accomplished because the transistor operates in either the cut-off or saturation state. Test apparatus was built to study and evaluate the circuit.

3.14 Printed Cables and Harnesses

(U) As stated in reference 2, item 2.11, two bids were received and a third one was expected on a proposal for the development of flat, flexible, multiconductor cables in 500-ft lengths. Each cable was required to comprise a 0.008-in.-thick polyester matrix in which were embedded 30 flat copper conductors 0.025 in. in width and spaced 0.045 in. from center to center. The third proposal did not materialize and, hence, testing of the two cables submitted by IRC and Tape Cable Corporation was started. The tests will include electrical, physical, and chemical measurements.

3.15 Antennas

(U) Two techniques for reducing the size of telemetering antennas are being investigated. In both cases, linear dimensions are cut approximately in half. The first approach uses capacitance loading; the second uses ferrite materials for inductive loading (see ref 2, item 2.7).

(U) In the first approach, an antenna-amplifier combination for the 235-260 mc range was built during this quarter. It is being readied for tests of efficiency, bandwidth, and antenna pattern. This amplifier should be capable of power outputs up to about 250 w. Some difficulty is being experienced because of the high input capacitance of the tube

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(4X250) being used. A coaxial impedance transformer is being designed to provide the impedance match between driver and amplifier.

(U) A smaller model designed to operate at 950 mc is being developed for the Penning Altimeter project. This unit will combine a plate-pulsed oscillator with the antenna. A model of this unit has been completed, and is being tested, but no data are available.

(U) In the second approach, a contract (DA-42-186-502-ORD-548) has been let to Sperry Microwave Electronics Company for materials development. The preliminary work consists in the fabrication of representative compositions of a family of ferrite-like materials having hexagonal crystal structure and a preferred plane of magnetization. It should be possible to produce a material of higher permeability and lower loss at higher frequency than comparable ferrites. The antenna work under this project has ceased pending availability of materials.

3.16 Thin-film Capacitors and Resistors

3.16.1 Vacuum-deposited capacitors:

(U) Breakdown strength and other properties may be greatly affected by penetration of the vacuum-deposited counter electrode into pinholes in the dielectric film. An additional group of SiO-dielectric capacitors was therefore made. Half of the group had standard vacuum-deposited Au counter electrodes, and the other half had counter electrodes made from an uncured silver-filled epoxy resin which should not penetrate the pinholes. Breakdown strength and other properties will be compared for both types.

3.16.2. Vacuum-deposited resistors:

(U) Several groups of nichrome film resistors have been vacuum-deposited onto glass. Resistivity ranged from 50 to 4,700 ohms/sq following accelerated aging treatment at 250°C for 10 min. Over a period of 3000 hr, values were stable within $\pm 22\%$, the majority being within $\pm 10\%$. These values are believed to be adequate for microcircuits now being considered.

3.16.3. Electroless deposition of nickel-film resistors:

(U) The deposition of resistive films of metallic nickel is being investigated as a means of producing resistors for the fabrication of "2-D" circuitry. Resistive films were produced on sensitized glass slides by immersing them in an electroless nickel bath. Films with resistivities of about 500 ohms/sq were deposited reproducibly from solution at 50°C. Decreasing the deposition temperature to 44°C raised the resistivity of films to 1 - 10 kohms/sq.

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4. METHODS, PROCESSES AND TECHNIQUES

4.1 Spray-etching

(U) The stainless steel spray etcher, which employs ammonium persulfate as etchant, was used to etch boards on which the patterned area was protected either with plated solder or with photoresist. The solder-plated boards etched satisfactorily. However, the spray was too forceful for boards protected with photoresist and the patterns broke down. Plans to modify the spray etcher to correct this trouble are being delayed pending collection of the latest information on commercial spray etchers.

4.2 External Effort on "2-D" Wafers

4.2.1 Pilot-lot Production of "2-D" Wafers

(U) Late in the preceding quarter, a contract was let for the manufacture of 200 "2-D" binary counters by current DOFL techniques. During the present quarter, discussions were held with the contractor and work was initiated by the company. Delivery is expected to begin by December 1959.

4.2.2 R&D on "2-D" Wafers

(U) The purposes of this contract are to conduct research and development leading to a refinement of the microminiaturization techniques pioneered by DOFL, and to determine their value and reproducibility by assembling experimental sample quantities of a basic binary counter. Available alloy, diffused base, and mesa transistors will be modified, as required, to adapt them for use with certain techniques, such as vacuum deposition of leads and photolithography, which may be employed in processing the circuit modules.

(U) The contract was let in the previous quarter. Work to date has involved the investigation of various encapsulating materials for cementing the transistors in the "2-D" plate. Hysol 6020 was found to produce the least change in the small signal parameters of the Philco 2N501 germanium micro-alloy-diffused transistor.

(U) Progress was made in working out techniques for sputtering tantalum on an insulating substrate for ultimate use as resistance elements and tantalum printed capacitors. These films are most easily applied by cathodic sputtering because they are too refractory for simple vacuum evaporation. These films can be reproducibly deposited in layers having resistivities ranging from 5 to 4000 ohms/sq.

(U) Aluminum has been chosen as the material for use as conducting leads because of its high conductivity, good corrosion resistance, ease of deposition, and low cost.

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